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NOTES ON TESTING THE EXPLOSIBILITY OF COAL DUSTS AND A PROPOSAL TO HAVE AN INTERNATIONAL TEST METHOD

BY

GEORGE S. RICE AND H. P. GREENWALD

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NOTES ON TESTING THE EXPLOSIBILITY OF COAL DUSTS AND A PROPOSAL TO HAVE AN INTERNATIONAL TEST METHOD[1]

By George S. Rice[2] and H. P. Greenwald[3]

The following paper was presented at an International Conference on Mine Safety Research held at Dortmund, Germany, September 23-28, 1935, inclusive. This conference was attended by representatives of Belgium, France, Germany, Great Britain, and the United States and, by invitation, Czechoslovakia, Poland, Spain, and Russia.

The first international conference of representatives of mine-safety research stations was held at the United States Bureau of Mines Pittsburgh Experiment Station in 1912.[4]

In 1924, the Safety in Mines Research Board of Great Britain entered into cooperation with the United States Bureau of Mines for interchange of research workers, of materials, of instruments for standardized testing, and of progress reports on problems of mutual interest. In 1929, the Safety in Mines Research Board undertook similar though more limited cooperative agreements with the French experiment station at Montlucon and the Belgian station at Frameries.

The favorable results of these cooperative arrangements led the Board to invite officials in charge of mining research at experimental stations in Belgium, France, Germany, the United States, Czechoslovakia, and Poland to attend a conference at Buxton, England, in July 1931.[5] Representatives of the last two countries were unable to attend. At this conference, a further agreement was made and subsequently officially approved by the countries represented for an international interchange of confidential quarterly reports and of special reports on research in mine safety and health. This interchange still continues.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6878".

2/ Chief mining engineer, U. S. Bureau of Mines.

3/ Senior physicist, U. S. Bureau of Mines.

4/ Rice, G. S., International Conference of Mine Experiment Stations, Pittsburgh, Pa., September 14-21, 1912: Bull. 82, Bureau of Mines, 1914, 99 pp.

5/ Safety in Mines Research Board of Great Britain, International Conference on Safety in Mines at Buxton, 1931: Paper 74, 1932, 67 pp.
Rice, G. S., International Conference on Mine-Safety Research at Buxton, England, July 1931. Inf. Circ. 6670, Bureau of Mines, 1932, 19 pp.

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The third international conference of this kind was held at Montlucon, France, in 1933, but the United States was unable to send a representative at that time. The fourth conference was held at Dortmund as mentioned, and the present paper was presented there by the senior author. It proposes standardization of methods of testing the relative inflammability of coal dusts, beginning on a laboratory scale. This proposal was unanimously approved. The papers and discussions of the Dortmund meeting probably will be published in the German language only, and it seems advisable that the Bureau of Mines publish them in English with such minor changes as may be made necessary by the manner of publication.

NOTES ON TESTING THE EXPLOSIBILITY OF COAL DUSTS

Before considering questions of standardization, the authors of this paper examine some of the underlying principles of large-scale testing of the explosibility of coal dust and their relation to conditions in commercial mines. The term "explosibility" is used here with the meaning attached to it by investigators of the United States Bureau of Mines in the field and in large-scale test work and is equivalent to the British term "inflammability", which, in Bureau of Mines work, is reserved for use in tests in which combustion of the coal dust does not extend beyond the sphere of influence of the source of ignition. Laboratory tests fall in this category.

INITIATION OF A COAL-DUST EXPLOSION

By definition, this phase of a coal-dust explosion covers the period during and the area in which the source of ignition is active. Whether or not the incipient explosion may be self-sustaining outside these limits is discussed later. Coal dust being present initially, either naturally in a mine or by provision of the investigator for his test, two things are needed to initiate an explosion - first, a means of dispersing the dust as a cloud in air and, second, a means of igniting the dust cloud. These may be condidered separately.

Formation of a Coal-Dust Cloud

A concussion or disturbance of some kind is needed to raise quiescent dust and disperse it in air. In commercial mines, this dispersion can occur either with or without a source of ignition of the cloud being present; details need not be presented to an assembly familiar with the numerous ways in which this can happen. Although the Bureau of Mines also experiments with electric-arc ignition of coal dust raised in a dense cloud by a blast of air, this paper will deal only with the case in which the source both raises and ignites the dust cloud, as by blow-out shots of explosives or by gas explosions. This is the system used in all extended series of large-scale tests of which the authors have knowledge.

Energy must be expended to form a cloud from quiescent dust, and the quantity of energy required will vary with the specific gravity of the dust, size of the particles, condition of the surface of the particles insofar as

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dispersion is affected by such things as electrostatic charges and moisture films, relative amount of inert dust present, if any, location of the dust in the cross-section of the passageway in which the cloud is formed, and whether all the dust present or only a part thereof is dispersed. This energy must be supplied by the source of ignition. The dust-raising power of sources of ignition used by different investigators has varied widely in accordance with their respective ideas. Three sources (other than the one not yet standardized, namely, electric ignition of a premade dust cloud) have been used at the Experimental mine, differing principally in their ability to form a dust cloud.6/ The two factors, ability of the dust to be dispersed and power of the source to disperse it, are fundamental considerations in initiation of a coal-dust explosion, whether in a commercial mine or in a testing gallery.

Ignition of a Coal-Dust Cloud

Heat must be supplied by the source of ignition to bring the coal dust to its ignition temperature. Not all the heat available for this purpose is used thus. There are direct losses to the surrounding walls through heating of inert or incombustible particles in the dust cloud (such as rock dust) and through heating of coal dust present in excess of the amount that can be burned by the quantity of air present; the conditions of this last case preclude liberation of energy through combustion to balance that absorbed. Vaporization of moisture, either in the coal or on surrounding surfaces, may require an additional amount of energy. If these losses are large enough, all the heat may be dissipated before the ignition temperature of the coal dust is reached.

PROPAGATION OF A COAL-DUST EXPLOSION

By definition, the initiatory phase of a coal-dust explosion ends when the source of ignition ceases to supply energy; after this the explosion must be self-sustaining or become extinguished. The question is resolved into a balance between production of energy by combustion of coal dust and its use in maintaining the explosion plus dissipation through losses.

Production of Energy

The rate of production of energy in the form of heat depends entirely on the rate of combustion of the coal dust, and this will be influenced by (1) the initial rate established by the source of ignition, (2) the density of the coal-dust cloud, (3) the size of the coal-dust particles, (4) the uniformity of their dispersion, (5) their reactivity with oxygen, particularly as influenced by volatile-matter content, and (6) the presence in the cloud of nonreactive material such as inherent ash and moisture of the dust and admixed incombustible dust and water. In commercial mines any of these may vary widely in different instances. In large-scale testing it is desirable to keep all of them, except the one under investigation, as nearly constant as possible; but there are limitations to the possibility of doing this.

6/ For a description of these sources of ignition and their properties, see Rice, George S., Greenwald, H. P., and Howarth, H. C., Explosion Tests of Pittsburgh Coal Dust in the Experimental Mine, 1925 to 1932, Inclusive. U. S. Bureau of Mines Bulletin 369, 1933, pp. 13-25.

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Energy Consumed by the Explosion

If the explosion is to continue, energy must be consumed in three ways - (1) in formation of the dust cloud in advance of the flame, (2) in heating the coal dust to its temperature of ignition, and (3) in maintaining pressure in the zone behind the flame. The explosion will be extinguished if any one of these is absent. Combustion of the coal dust produces energy only in the form of heat, and for formation of a dust cloud the heat must be transformed to mechanical energy. This occurs through the agency of either pressure waves or bodily movement of masses of gas. Heat energy is used directly in bringing the coal dust to its ignition temperature. Maintenance of pressure behind the flame may result from the individual or concurrent action of residual heat and compression of the mass of gas present after combustion into less volume than it would occupy at normal temperature and pressure.

Loss of Energy

Losses accompany consumption of energy in the three ways mentioned above. The mechanical energy of pressure waves and gas movements is dissipated by friction of gases on walls and obstructions, is transferred to solid objects that are moved, and is lost by expansion at side openings. Heat is lost directly by transfer to the surrounding walls and other solid objects and by heating inert dust or coal dust in excess of that which can be burned by the available oxygen. Compressed gases behind the flame suffer losses by direct transfer of heat to the surroundings, by expansion under some conditions, and by mechanical action if the gases are moving. A_t times these losses may carry pressure below that of the atmosphere, and this may act to retard advance of the flame of the explosion.

SELECTION OF CONDITIONS FOR LARGE-SCALE TESTS

The investigator conducting large-scale tests of the explosibility of coal dust will wish to have his data directly applicable to conditions in commercial mines. From the foregoing it is evident that he must base his test methods on the conditions in those mines. As it is impractical if not impossible to attack the problem from the fundamental standpoint of production and dissipation of energy, he must concern himself instead with the secondary phenomena arising from the energy changes. This makes it necessary to reproduce in the test method the original mine conditions with as few alterations as may be possible. To test all the conditions in commercial mines under which coal-dust explosions may be initiated and propagated is an impossible and also an unnecessary task. Work may be concentrated on those conditions that are most dangerous and also are most likely to occur.

Experiments have shown that the factors influencing the energy changes may be grouped under seven heads: (1) Reactivity, particularly as related to the volatile ratio of the coal; (2) size (or specific surface) of the dust; (3) quantity of coal dust and inert dust present; (4) original location of the respective dusts in the cross section of the testing passageway; (5) inflammable gas in the air; (6) dust-raising and igniting power of the source of

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ignition; and (7) cross sectional area and shape of the testing passageway, its length, the presence of bends, obstructions, and openings of all kinds, and the character and condition of the walls, such as smooth or rough and wet or dry. It is desirable that the investigator be able to make changes in all of these at will, and difficulty usually will be experienced only with the seventh. The more nearly the conditions of the testing passageway approach those of a coal mine, the less uncertainty will there be in application of the test data. The United States Bureau of Mines published a summary of its findings under the above seven heads in 1929 in Technical Paper 464.1/ Additional work with Pittsburgh coal dust was set forth in Bulletin 369, to which reference has been made. There remain unpublished the data of tests of a number of different coals made since 1929.

After deciding under what conditions his tests shall be made, the investigator has choice of two general methods of procedure. He may view the problem from an abstract standpoint and determine the effect of each of the seven factors mentioned above within the limits between which they vary in commercial mines. The goal of such an investigation would be a mathematical expression combining all of them in such form that known values could be substituted after study of a commercial mine and the rock-dusting requirements of the mine or any portion thereof could be evaluated without further experiment. Attempts to do this have been made, but none has been completely successful so far because not all the factors were included. The authors believe that development of such an expression or mathematical formula is a desirable goal but that it can be accomplished only by far more extensive testing than has been done as yet.

It follows that until such a formula is available, large-scale tests of the explosibility of coal dust should be divided into groups according to the factor on which they give information, and due care should be taken to prevent inferences that are not warranted by the test conditions.

APPLICATION OF TEST DATA

Obviously, application of test data to a specific mine can be little more than a guess unless conditions in the mine in question are known, and this knowledge should embrace all of the seven factors detailed above. Recognition of this fact led to early development in the Bureau of Mines of methods of investigating coal-dust explosion hazards in both gassy and nongassy commercial mines. Particular attention is paid to possible sources of ignition and the conditions under which they may be active. The quantity and distribution of the dust are noted. Numerous dust samples are taken in working places and passageways so that particle-size tests and analyses in the laboratory give a reasonably satisfactory picture of these factors. The coal is sampled in place in the bed by standard methods to obtain the range of composition in different parts of the mine. Air samples are taken in all ventilating splits and in the main return to determine what allowance must be made for inflammable gas in estimating rock-dusting requirements. Then a quantity of specially mined coal, sufficient for large-scale tests, is taken from the coal bed under consideration and sent to the Experimental mine. The foregoing information is

1/ Rice, George S., and Greenwald, H. P., Coal-Dust Explosibility Factors Indicated by Experimental Mine Investigations, 1911 to 1929: Tech. Paper 464, Bureau of Mines, 1929, 45 pp.

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used to determine which tests are more important as well as to make application of the test data. The authors' experience leads them to believe that this branch of the work can scarcely receive too much attention and that it furnishes the only reliable method of making application of test data.

The question of probability of occurrence of a coal-dust explosion in the specific mine must be considered. For example, a mine may be extremely gassy, and there is a possibility that a large body of an explosive gas-air mixture may be ignited. On the other hand, the system of ventilation employed, the use of approved explosives, apparatus, and machinery, and the vigilance of the management in maintaining safe conditions may make an explosion quite improbable. Security against the propagation of a coal-dust explosion under any condition that can possibly occur in a mine having a very large inflow of gas might call for maintenance by rock-dusting of 75 or 80 percent inert matter in the mine dust; this would include inert matter naturally present. The judgment of the trained investigator enters here, as it will at other points, to provide adequate precautionary measures, and the authors believe that it will never be wholly supplanted.

COMPARISON OF TEST DATA OBTAINED BY DIFFERENT INVESTIGATORS

Different investigators have selected different test methods, each according to his particular needs or viewpoint. It is inevitable that one will obtain results differing from those of another who uses different methods. Discussions involving comparison of test data obtained in different countries are fruitless unless the differences in test methods are taken into account, and at present there is no entirely satisfactory way of evaluating these.

The authors suggest the desirability of all investigators adopting some standard method of test by which their work can be compared. It is not supposed that this method would supplant those now used by any investigator; the purpose is to obtain supplemental evidence, through use of a test made under an agreed standard, to provide a satisfactory and logical basis for the common evaluation of all large-scale tests.

Such a method assumes use by all investigators of a standard piece of testing equipment, and this must of necessity be relatively inexpensive. The authors suggest that, to begin with, it might well be on the laboratory scale.

Laboratory tests may have two purposes - (1) empiric reproduction of large-scale tests for routine purposes to save time or costs and (2) research work on such factors as are amenable to laboratory treatment. Fulfillment of the first purpose has been achieved in England and the United States through use of a device described below. With regard to the second purpose, laboratory testing can deal only with factors affecting the initiation of a coal-dust explosion, such as are enumerated on pages 2 to 3. The work that can be done on dust-cloud formation is evidently limited, and ignition of a preformed cloud will be a more fruitful field of work. It should be possible to determine relation of ignitibility to composition or reactivity, density of the dust cloud,

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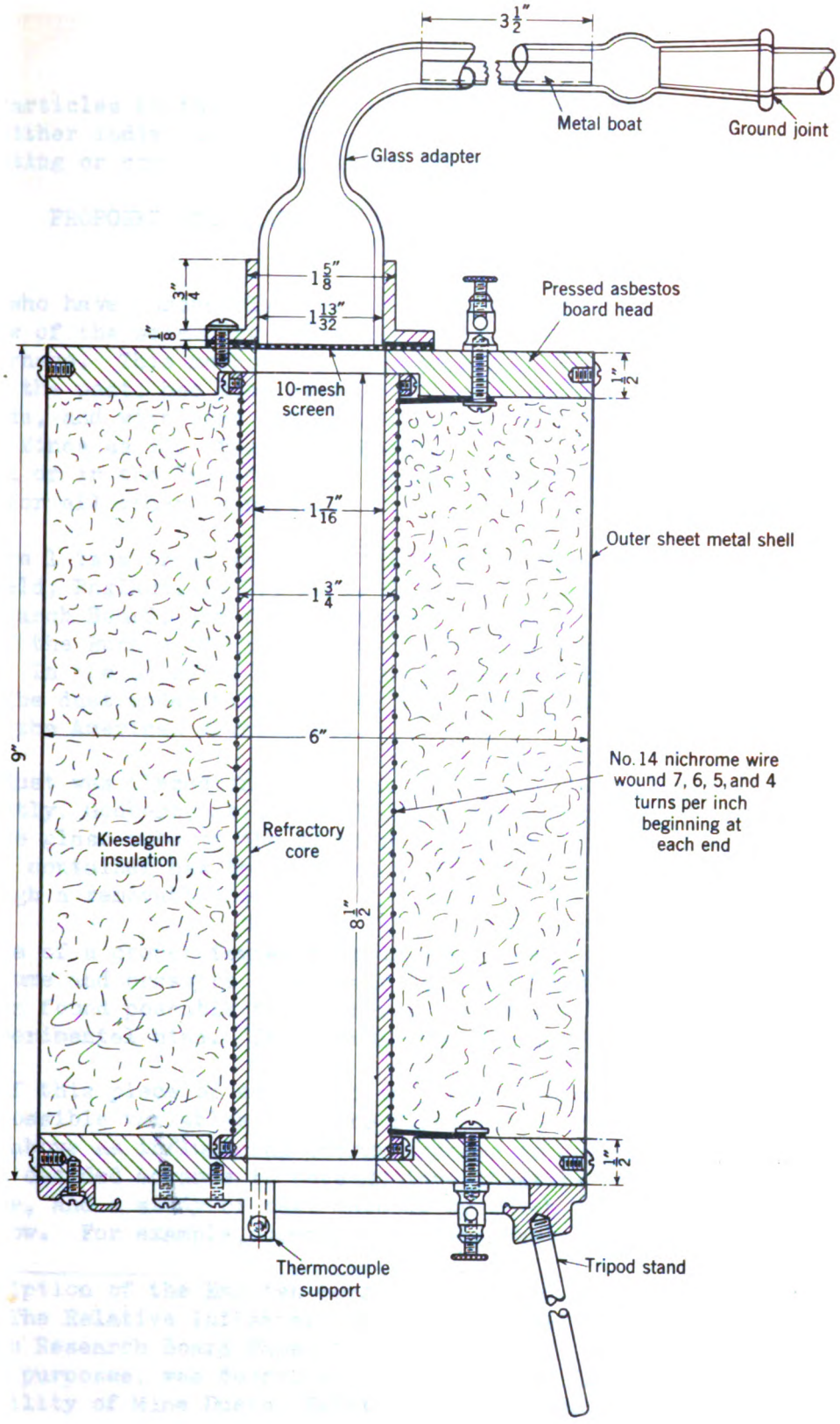

Figure 1.—Cross section of laboratory furnace for determining inflammability of small samples of dust.

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size of particles (within limits), and temperature and nature of the igniting source, either individually or in combination. The effect of added inert dust in preventing or controlling ignition can be studied also.

PROPOSED STANDARD METHOD OF TESTING INFLAMMABILITY OF COAL DUSTS

All who have pursued laboratory studies of the inflammability of coal dusts know of the method by which the dust to be tested is blown through a heated furnace. This method has been used in different forms by many investigators in the past, has been developed by the British investigators to meet their needs, and with some modifications has been adopted by the United States Bureau of Mines as its standard laboratory method. The apparatus used either in England or in the United States might possibly serve as a satisfactory standard for all other countries.

Figure 1 is a cross sectional view of the laboratory furnace developed at Sheffield, England, by Dr. A. L. Godbert, of the staff of the Safety in Mines Research Board, and further tested by him at the Pittsburgh Experiment Station of the Bureau of Mines. The furnace is cylindrical, with dimensions as shown. In the original English development, oxygen was used to blow a cloud of the dust under test through the furnace; air was substituted for oxygen in the American development.8/

The dust was placed in the metal boat shown in the glass adapter (fig. 1). More recently, Godbert, at Sheffield, has abandoned the boat and placed the dust in the glass tube to the right of the ground joint. At Pittsburgh, a metal dust container has been placed permanently in the apparatus at the location through a removable cover.

By use of a proper temperature in the furnace (720° C.) and adjustment of the volume and pressure of the air used to carry the dust into the furnace, it has been found possible to reproduce results of standard propagation tests in the Experimental mine. This development is for routine test purposes.

Use of this piece of equipment in a standard manner by all countries will leave as possible variables only the first three of the seven groups of factors mentioned above as influencing energy changes in coal-dust explosions. It would be a decided advance to have all investigators come to an agreement on these three, and a study of test methods by which the others might be attacked could follow. For example, comparative data through laboratory testing have

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8/ A description of the English work was given by Godbert, A. L., and Wheeler, R. V., The Relative Inflammability of Coal Dusts; A Laboratory Study: Safety in Mines Research Board Paper 56, 1929, 23 pp. A simpler form, for purely routine purposes, was described by Godbert, A. L., A Routine Test of the Inflammability of Mine Dusts: Safety in Mines Research Board Paper 68, 1931, 9 pp. The work at Pittsburgh is described by Godbert, A. L., and Greenwald, H. P., Laboratory Studies of the Inflammability of Coal Dusts; Effect of Fineness of Coal and Inert Dusts on the Inflammability of Coal Dusts: Bull. 389, Bureau of Mines, 1936, 29 pp.

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been obtained on the relative inflammability of different American and British coals by this method, and the test data are included in Bureau of Mines Bulletin 389. These data enable comparisons to be made with large-scale test results obtained on the same coals at the respective stations. It is suggested that for mutual benefit each investigator should parallel any series of large-scale tests made at his respective station with tests in the laboratory, unless the variations whose influence is being studied on the large scale can not be reproduced in the laboratory tests. The laboratory work should include a series of special tests made under an agreed method that might be revised from time to time by mutual consent.

SUMMARY AND RECOMMENDATION

The authors' experiences with and beliefs concerning large-scale tests of the explosibility of coal dust may be summarized as follows:

1. The continuance of a coal-dust explosion depends on production of sufficient heat by combustion of coal dust to provide the thermal and mechanical energy requisite for the process and at the same time provide for the loss of energy to surroundings that is inevitable.

2. It is not possible to study coal-dust explosions from the standpoint of production, consumption, and loss of energy, and secondary phenomena must be observed.

3. Conditions governing energy changes in coal-dust explosions vary widely in commercial mines, and the investigator should have thorough knowledge of these before fixing the conditions of his large-scale tests.

4. The data obtained by different investigators have been inconsistent at times because test methods were not comparable and knowledge by which they could be harmonized has not been available.

5. The results obtained by different investigators can be correlated if all will adopt and use (for reference purposes only) some simple test method and equipment.

6. A start can be made by use of the laboratory furnace method of testing dusts; this already has been done by American and British investigators. By means of it, an agreement should be reached on the influence of size and composition or reactivity of coal dust.

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